GOLF BALL LOCATION SYSTEM

BACKGROUND

[0001] Attempts to successfully manufacture and market a golf ball having an embedded radio transmitter for radio location of a lost ball have been unsuccessful. The lack of success may be due to the severe conditions under which golf balls are traditionally made (high pressures and temperatures), and the severe conditions golf balls endure during play (high impact G-forces). The production of radio transmitters having closely controlled and stable center frequencies that remain stable under ball construction and play conditions may be extremely difficult.

[0002] Golf balls containing sensors to trigger radio frequency transmitters may be useful in the game of golf, as a lost ball constitutes a penalty in score, as well as the obvious loss of the ball itself. Golf balls that emit radio signals for a few minutes after being struck can be located with a simple radio receiver. The integration of a radio transmitter with precise frequency control into a golf ball is complicated by the extreme shock balls encounter during play. Such harsh conditions make the use of accurate but fragile components problematic.

[0003] A radio embedded in a golf ball may use either a quartz crystal or a free running oscillator to accurately generate and control the golf ball's transmitter center frequency. Incorporation of a quartz crystal oscillator into a golf ball may be unfavorable from both cost and durability points of view. Crystals typically represent a sizable portion of the cost of the circuits that employ them. Additionally, crystals are very susceptible to damage from impact forces such as those applied to golf balls during manufacturing and normal use. Solutions to protect a crystal from damage (e.g., insulating circuitry from shock forces) may reduce the probability of potential damage but may also significantly increase the part and manufacturing costs of a golf ball. Furthermore, the cost of a high-reliability quartz crystal oscillator that is able to withstand the shock experienced during play may be cost-prohibitive.

[0004] Therefore, it may be desired to have a durable, interference resilient transmission and detection system contained within a golf ball. Further, it may be desirable to operate such a system with a free-running oscillator.

SUMMARY OF THE INVENTION

[0005] Embodiments of the present invention relate to a golf ball and a golf ball location system that assists in the recovery of golf balls lost during a game of golf. The golf ball may include a transmitter circuit capable of transmitting within a determined bandwidth, a bandwidth that is wide enough to negate frequency drift of various transmitter components. In some embodiments, a transmitter modulates a signal at an audible rate.

[0006] The location system may include a receiver circuit capable of receiving a signal at or near a designed center frequency. In some embodiments, a receiver has an input bandwidth that is narrower than the transmitter's output bandwidth. In some embodiments, a receiver has an input band that traverses a wider band at a sub-audible rate.

[0007] In accordance with embodiments of the present invention, a system for locating a golf ball comprises: the golf ball having an encapsulated transmitter that modulates an audible signal to an output band, wherein the output band defines an output bandwidth; and a receiver having an input band defining an input bandwidth wherein a center frequency of the input band of the receiver is variable; wherein the input bandwidth is smaller than the output bandwidth.

[0008] In accordance with some embodiments of the present invention, a golf ball comprises: an encapsulated transmitter that modulates an audible signal to an output band; wherein the output band defines an output bandwidth and the transmitter includes a free running oscillator having an inductor and a capacitor.

[0009] In accordance with other embodiments of the present invention, a method to locate a golf ball using a golf ball location system having a transmitter encapsulated in a golf ball and a receiver, the method comprises: modulating an audible signal with the transmitter; transmitting the modulated signal to an output band; providing a receiver with an input band, wherein the input band is narrower and within the output band; receiving an input signal residing within the input band; and varying a center frequency of the input band to traverse the output band.

[0010] In some embodiments of the present invention, a state of the power source or battery of the golf ball is communicated by the golf ball.

DESCRIPTION OF DRAWINGS

[0011] FIGURE 1 shows a cutaway perspective view of a golf ball containing an encapsulated transmitter, in accordance with embodiments of the present invention.

[0012] FIGURES 2A through 2D graphically relate frequency tolerances and bandwidths of a transmitter and receiver, in accordance with embodiments of the present invention.

[0013] FIGURES 3A and 3B relate a transmitter's output band to an example modulation waveform, in accordance with embodiments of the present invention.

[0014] FIGURES 4A through 4C relate a transmitter's output band to a receiver's input band and an example modulation waveform, in accordance with embodiments of the present invention.

[0015] FIGURES 5A and 5B show block and schematic diagrams of a transmitter in accordance with embodiments of the present invention.

[0016] FIGURE 6 shows a schematic diagram of an embodiment of a receiver in accordance with the present invention.

[0017] FIGURE 7 shows a plan view of a printed circuit board (PCB) having an etched inductor in accordance with embodiments of the present invention.

[0018] FIGURE 8 shows a cross sectional view of a PCB according to some embodiments of the present invention.

[0019] FIGURE 9 shows a perspective view of transmitter module to be encapsulated within the core of a golf ball in accordance with embodiments of the present invention.

DESCRIPTION OF INVENTION

[0020] It is well-known that many golf balls are lost during play when golf balls land in particularly overgrown areas of a golf course. The loss can occur even though the ball may have been visible during its entire flight and the approximate region of the landing of the ball is known. The loss of a golf ball not only entails financial loss to the player it also means that the player is put at a disadvantage as far as game scoring is concerned. The present invention aids in

reducing the occurrence of lost golf balls. Players employing golf balls that can be more readily recovered are at an advantage both financially and by avoiding unnecessary point loss.

[0021] To provide a locatable golf ball, a free running oscillator having an inductor and a capacitor to set a transmitter's center radio frequency may be used. Free running oscillators, however, may suffer from excessive tolerance problems. Some free running oscillators are constructed from tank circuits having a capacitor and an inductor placed in parallel. Cost effective capacitors have a wide range of acceptable tolerances in the order of ±5%. Etched inductors similarly have a wide range of acceptable tolerances in the range of ±2% due to variables of etching. Wire wound coil inductors have an even wider range of acceptable tolerances.

[0022] To improve accuracy, some components are tunable. Etched inductors may utilize various tuning methods, such as, e.g., using a conductive disk or a "tuning slug". Tuning slugs, however, may be large, expensive and suffer the disadvantage of potentially being disturbed during subsequent encapsulation. Tunable free running oscillators typically require careful adjustment prior to encapsulation and final ball molding. Even after careful adjustment, components may drift due to the pressures and temperatures of final manufacturing and molding, and due to the ultimate abuse of play. Under such conditions a circuit may have an ultimate operating frequency that can easily drift by several percent from its factory set frequency. These variations may be far outside the normal modulation input bandwidths of traditional receivers.

[0023] One solution to combat the variations of free running oscillators is to use a transmitter that masks the variations by transmitting over a wide frequency bandwidth. Such a transmitter may have an output bandwidth that is substantially larger the potential frequency variation of the oscillator. A receiver may be designed to operate over a similar substantially wide or wider bandwidth. In such designs, even if the output band of the transmitter and the input band of the receiver do not exactly align, a majority of the transmitter's output bandwidth fall within the receiver's input band.

[0024] Unfortunately, such receivers, which have an input bandwidth nearly equal to or greater than the transmitter's output bandwidth, leave the receiver open to interference from any

strong signal that falls within the receiver's input band. Furthermore, wide band transmitters typically use more power than their narrower band counterparts.

[0025] FIGURE 1 shows a cutaway view of a golf ball 10 containing an encapsulated transmitter region 20. The encapsulated transmitter 20 is surrounded by molded rubber 30 that is enclosed by a molded cover 40. A transmitter 100 within the encapsulated transmitter region 20 is positioned within the golf ball 10 during the manufacturing process. Rather than including a transmitter employing a fragile crystal, embodiments of the present invention may use an inexpensive inductive-capacitive (LC) tank circuit, which resonates at or near a desired carrier frequency. By eliminating the crystal, the golf ball 10 may have improved resiliency against impact damage and shock absorbing packaging may be reduced or omitted.

[0026] According to some embodiments of the present invention, even if the center frequencies of a transmitter and a receiver have drifted from their designed center frequencies, for example, due to manufacturing variations, environmental conditions and/or normal wear, the transmitter-receiver pair utilizes a modulation technique to overcome these frequency uncertainties. A transmitter 100 transmits within a wide band and a complementary receiver has an input bandwidth that is narrower than the transmitter's output bandwidth.

[0027] Some embodiments include a golf ball having a transmitter that modulates a signal having audible frequencies. The transmitter modulates the signal having audible frequencies across the transmitter's output band. Frequencies between 20 Hz and 20 kHz are called the audible frequencies. A signal having an audible repetition rate includes periodic signals that repeat at an audible frequency. A signal having an audible repetition rate forms a signal having audible frequencies. A periodic signal having an audible repetition rate between 20 Hz and 20 kHz repeats every 50 microseconds to 50 milliseconds. For example, a signal may be a gradually rising or falling saw-tooth waveform repeating at an audible rate between 20 Hz and 20 kHz, thereby repeating every 50 microseconds to 50 milliseconds. Alternatively, a signal having audible frequencies may be formed by a signal having a changing frequency. For example, the signal may be a waveform having a center frequency that changes by incrementally increasing and/or decreasing its center frequency among a set of values between 20 Hz and 20 kHz.

[0028] In some embodiments, a transmitter's output band is greater in spectral width than the receiver's input band. For example, the transmitter's output band may span several MHz and the receiver's input band may span several hundred kHz. By using a receiver with a front-end having a narrower bandwidth that the full transmitter's bandwidth, a receiver may substantially decrease the probability that it receives unwanted signals that interfere with proper detection of a golf ball's transmitted signal.

[0029] In some embodiments, the receiver's input bandwidth represents between 2 and 8 percent of the transmitter's output bandwidth. For example, a transmitter may have an output bandwidth between 4 MHz to 5 MHz and a corresponding receiver may have an input bandwidth between 100 KHz to 300 KHz. In some embodiments, the receiver's input bandwidth represents less than 50 percent of the transmitter's output bandwidth. In some embodiments, the receiver's input bandwidth represents between 5 and 20 percent of the transmitter's output bandwidth. In some embodiments, the receiver's input bandwidth is less than 5 percent. In other embodiments, the receiver's input bandwidth is greater than 50 percent of the transmitter's output bandwidth.

[0030] In some embodiments, a detection unit includes a receiver that has a stationary input band or input window. In other embodiments, the receiver has an input window that traverses at least a part of the transmitter's output band at a sub-audible rate. By sweeping a receiver's input band across a transmitter's wider output band, a receiver is not permanently impaired by a stationary interfering signal. As a result, precise frequency alignment between the transmitter and receiver is not necessary when using the present invention.

[0031] A sub-audible rate is a rate between 0 Hz and 20 Hz. For example, a 20 Hz input window, which traverses a spectrum at a sub-audible rate of 20 Hz, traverses the spectrum every 50 milliseconds. An input window that traverses a spectrum at 0.5 Hz cycles through a spectrum every 2 seconds.

[0032] In some embodiments, a receiver traverses its input window using a periodic waveform, e.g., a saw-tooth or triangular waveform. In some embodiments, a receiver traverses its input window with a periodic waveform having a period greater than or equal to approximately 50 milliseconds, such as a period set between 50 milliseconds and 10 seconds, or

more particularly between 200 milliseconds and 5 seconds, or even more particularly, between one-half second and 2 seconds.

[0033] In some embodiments, the receiver has an input window that traverses the entire designed output band of a transmitter. In other embodiments, the receiver has an input window that is a fraction as wide as the transmitter's output band and traverses only a portion of the designed output band of a transmitter. The portions of the transmitter's output band that the receiver does not traverse form a guard band, which is used to insure that the receiver's window falls within the transmitter's output window. A larger guard band allows a design to use components with wider tolerances and allows for drifts in component values over time and use.

[0034] For example, a transmitter is designed with an output band that is 5 MHz wide. A corresponding receiver traverses its input window across only 2 to 3 MHz of the entire 5 MHz bandwidth of the transmitter. A receiver having an input window that is 300 kHz wide receives a signal from a transmitter that has a transmission band that is 5 MHz wide. The receiver may slide its input window across just the center 3 MHz of the 5 MHz wide transmission window. This receiver may traverse its input window across the 3 MHz sub-window once every second or equivalently at a sub-audible rate of 1 Hz. This design forms a 1 MHz guard band at each end of the transmitter's output window. The guard band allows for substantial drift in component values.

[0035] Some embodiments include both a golf ball that modulates an audible rate signal and a detection unit having an input window that traverse a band at a sub-audible rate. The golf ball includes a transmitter that modulates an audible signal to an output band. The detection unit includes a receiver that has an input window that traverses at least a portion of the transmitter's output band periodically at a sub-audible rate.

[0036] In some embodiments, the ratio between the audible repetition rate of the periodic signal and the sub-audible rate at which the receiver's input window traverses the transmitter's output window is set to a value between 20000-to-1 and 10-to-1, or more particularly between 2000-to-1 and 50-to-1, or even more particularly between 400-to-1 and 100-to-1.

[0037] In some embodiments, once activated, a golf ball 10 transmits a signal that sweeps between two frequencies about the actual center frequency of the golf ball. The transmitted

signal sweeps across a transmit band. If a receiver has a narrower bandwidth than the transmitter, the transmitter will eventually transmit a signal that passes through the narrower input band of the receiver.

[0038] In some embodiments, prior to encapsulating the transmitter 100, the transmitter 100 is adjusted to transmit with a predetermined center frequency by modifying the inductor's inductance. Etch inductors may be tuned using conductive disks. Coil inductors may be tuned by bending the coil turns. Once tuned, the inductor may be encapsulated.

[0039] The frequency modulation bandwidth of the transmitter may be designed wide enough to account for: (1) the transmitter's expected maximum center frequency deviation during molding, temperature and service; (2) the expected maximum receiver frequency tolerance; and (3) the width of the input band of the receiver.

[0040] In some embodiments, a receiver used to detect a golf ball may use a receiver having at a fixed center frequency. In other embodiments, a receiver has a varying center frequency. The varying center frequency may oscillate between an upper bound and a lower bound at a sub-audible rate, e.g. 1 Hz or 2 Hz. A window, which represents the input band of the receiver, thereby cycles across the output band of the transmitter at the sub-audible rate. Embodiments that sweep or cycle the input window of the receiver across the output band of the receiver help to reduce the adverse effects of interfering signals and also reduce the need for well tuned components in both the transmitter and receiver.

[0041] FIGURES 2A through 2D graphically relate center frequency tolerances to output bandwidth BW_{Tx} and input bandwidth BW_{Rx} of the transmitter 100 and receiver, respectively. Both the transmitter 100 and receiver are designed to work at a center frequency of $f_C = f_{designTxC} = f_{designRxC}$. FIGURE 2A shows a designed center frequency $f_{designTxC}$ of a transmitter 100 may vary within a tolerance from a low of $f_{designTxC\_Low}$ to a high of $f_{designTxC\_High}$. Drift and variations in a transmitter's center frequency are due to several factors, including component tolerances, manufacturing conditions, usual ball wear, and operating conditions.

[0042] FIGURE 2B illustrates an output band of a transmitter 100. The transmitter 100 has a transmit bandwidth BW_{Tx} that is centered on $f_{actualTxC}$. The actual transmitter output band low and high frequency limits are $f_{actualTxLow}$ and $f_{actualTxHigh}$, respectively. The output bandwidth

BW_{Tx} is the difference between $f_{TxActualHigh}$ and $f_{TxActualLow}$: $BW_{Tx} = f_{TxActualHigh} - f_{TxActualLow}$. A transmitter may emit a signal anywhere within its output bandwidth.

[0043] FIGURE 2C shows a center frequency of a receiver may vary from a low of $f_{desighRxC\_Low}$ to a high of $f_{desighRxC\_High}$. Again, the drift and variations may be due several factors, including component tolerances, manufacturing conditions and operating conditions.

[0044] FIGURE 2D illustrates an input band determined by design of a receiver. The receiver has an input bandwidth BW_{Rx} that is centered on $f_{actualRxC}$. The actual receiver input band low and high frequency limits are $f_{actualRxLow}$ and $f_{actualRxHigh}$, respectively. The input bandwidth BW_{Rx} is the difference between $f_{RxActualHigh}$ and $f_{RxActualLow}$: $BW_{Rx} = f_{RxActualHigh} - f_{RxActualLow}$. A receiver may detect signals anywhere within its input bandwidth.

[0045] A transmitter 100 is designed to transmit at a center frequency of $f_{designTxC}$ but in fact has an actual transmitter center frequency $f_{actualTxC}$, which falls anywhere between $f_{designTxC\_Low}$ and $f_{designTxC\_High}$. Similarly, a receiver is designed to receive at a center frequency of $f_{designRxC} = f_{designTxC}$ but in fact may have an actual receiver center frequency $f_{actualRxC}$, which falls anywhere between $f_{actualRxLow}$ and $f_{actualRxHigh}$ and may be different from the actual transmitter center frequency.

[0046] In operation, a receiver's input band may be designed to fall entirely within a transmitter's output band even when the center frequency of the transmitter 100 has drifted. For example, a transmitter 100 may have a center frequency that has drifted in one direction and the receiver may have a center frequency that has drifted in the other direction. To select an appropriate transmitter output bandwidth BW_{Tx} knowing that center frequency variations are possible, one may consider the worst case frequency drifts along with a predetermined receiver input bandwidth BW_{Rx}. The worst scenarios occur when the transmitter 100 and receiver have center frequencies that drift to extremes in opposite directions. However, even when a portion of the receiver's input band falls outside of the transmitter's output band, the signal from the transmitter may still be detectable.

[0047] The lower boundary of the output band $f_{actualTxLow}$ of the transmitter 100 may be determined by assuming the transmitter 100 has an actual center frequency $f_{actualTxC}$ that has drifted up to an extreme center frequency $f_{designTxC\_High}$ and the receiver has an actual center

frequency $f_{actualRxC}$ that has drifted down to an extreme center frequency $f_{designRxC\_Low}$. The spectral distance between the transmitter's actual center frequency $f_{actualTxC}$ and the receiver's actual center frequency $f_{actualRxC}$ is: $(f_{actualTxC} - f_{actualRxC})$, and in this extreme case is $(f_{designTxC\_High} - f_{designRxC\_Low})$. The lower boundary of the output band $f_{actualTxLow}$ is equal to the transmitter's actual center frequency less this spectral distance less half the width of the receiver's input bandwidth: $f_{actualTxLow} = \{f_{actualTxC} - (f_{designTxC\_High} - f_{designRxC\_Low}) - 0.5*(BW_{Rx})\}$.

[0048] Similarly, the upper boundary of the output band $f_{actualTxHigh}$ of the transmitter 100 may be determined by assuming the transmitter 100 has an actual center frequency $f_{actualTxC}$ that has drifted down to the other extreme center frequency $f_{designTxC\_Low}$ and the receiver has an actual center frequency $f_{actualRxC}$ that has drifted up to an opposite extreme center frequency $f_{designRxC\_High}$. The spectral distance between the transmitter's actual center frequency $f_{actualTxC}$ and the receiver's actual center frequency $f_{actualRxC}$ is: $(f_{actualRxC} - f_{actualTxC})$, and in this extreme case is $(f_{designRxC\_High} - f_{designTxC\_Low})$. The upper boundary of the output band $f_{actualTxHigh}$ is equal to the transmitter's actual center frequency plus this spectral distance plus half the width of the receiver's input bandwidth: $f_{actualTxHigh} = \{f_{actualTxC} + (f_{designRxC\_High} - f_{designTxC\_Low}) + 0.5*(BW_{Rx})\}$.

[0049] The lower and upper boundary thereby defined the transmitter's output bandwidth: $BW_{Tx} = (f_{actualTxHigh} - f_{actualTxLow})$, which equals $[\{f_{actualTxC} + (f_{designRxC\_High} - f_{designTxC\_Low}) + 0.5*(BW_{Rx})\} - \{f_{actualTxC} - (f_{designTxC\_High} - f_{designRxC\_Low}) - 0.5*(BW_{Rx})\}]$, which simplifies to $[(f_{designTxC\_High} - f_{designTxC\_Low}) + (f_{designRxC\_High} - f_{designRxC\_Low}) + BW_{Rx}]$, or equivalently to the variation in the transmitter plus the variation in the receiver plus the receiver's input bandwidth.

[0050] If a transmitted signal sweeps across the full transmit modulation bandwidth of the transmitter, that is from $f_{actualTxLow}$ to $f_{actualTxHigh}$, a receiver having a narrower input band that falls within the transmitter's output band will periodically receive the transmitted signal.

[0051] FIGURES 3A and 3B relate a transmitter's output band to an example modulation waveform. FIGURE 3A shows a transmitter's output transmission band having a bandwidth of BW_{TX}. FIGURE 3B shows one possible modulation waveform of a transmitter 100. As time progresses, the modulation waveform, shown as a saw-tooth wave, is modulated by frequency modulation (FM). As the saw-tooth wave value increases from a minimum value to a maximum valve, the FM transmitter generates a peak that sweeps from frequency $f_{actualTxLow}$ to frequency

$f_{actual\ TX\ High}$. Once the maximum value is reached, the process repeats again starting from the minimum value.

[0052] For example, a signal having frequency f_1 is transmitted at time t_1. As time progresses from t_1 to t_2, the frequency of the transmitted signal progresses from f_1 to f_2. An ever increasing frequency is transmitted until the upper end of the transmitter's output band is reached. Once the saw-tooth wave reaches its maximum value and returns to its minimum valve, the FM transmitter effectively generates a signal that restarts from a frequency $f_{actualTxLow}$. The cycle of generating an increasing then resetting frequency signal continues as long as the saw-tooth modulation signal persists.

[0053] FIGURES 4A through 4C relate a transmitter's output band to a receiver's input band and provide an example modulation waveform. FIGURE 4A shows a transmitter's output band having a bandwidth of BW_{TX}. FIGURE 4B shows a receiver's input band having a narrower bandwidth of BW_{RX} that falls within the transmitter's output band. FIGURE 4C shows ranges of time when a receiver detects a transmitted signal within its input band. The receiver receives a passing peak of energy as the transmitted signal sweeps through the receiver's input band. Two durations of time during which the receiver detects the transmitted waveform are shown. The first duration occurs as the signal generated by the transmitter 100 sweeps between $f_{actualTxLow}$ and $f_{actualTxHigh}$. During this period the frequency transmitted falls within the actual receiver input band. The second duration occurs as the transmitter resets and sweeps again. During these durations of time, the receiver detects the transmitted signal.

[0054] In the example illustrated, the transmitter modulates a saw-tooth signal. Additionally, the center frequencies of the transmitter and receiver may be slightly skewed. The resulting demodulated signal, when converted to an audible signal, may be masked by the monotonic nature of the saw-tooth waveform.

[0055] Alternatively, the transmitter could modulate a triangular signal. If the center frequencies of the transmitter and receiver are slightly skewed, the resulting demodulated signal, when converted to an audible or visual signal, may be perceived as a series of double bursts. By comparing the elapsed time between the double bursts and between successive sets of double

bursts, one can determine the aggregate drift between the transmitter and receiver center frequencies.

[0056] The saw-tooth waveform shown in FIGURES 3B and 4C may be replaced by any number of modulation waveforms. A monotonic waveform that simply increases from frequency $f_{actualTxLow}$ to frequency $f_{actualTxHigh}$ then restarts increasing from frequency $f_{actualTxLow}$ again, such as the saw-tooth waveform, would also mask the effects of drift and differences between the transmitter and receiver center frequencies. Alternatively, a sinusoidal wave, triangular wave, a monotonically increasing potentially periodic waveform or the like may be used. Alternatively, other periodic waveforms (having a repetition rate of, for example, 20 Hz to 20 kHz, or more particularly 60 Hz to 2 kHz) may be used. The frequency of the modulation waveform may be intentionally set to a low frequency but below the upper limit of the audio range. Modulated signals received by the receiver through the receiver's input band are received at a rate within the audio frequency range. An operator can "home in" on the lost golf ball by listening for effects of the ball's modulation signal. A retractable antenna on the detector unit may be used to adjust the receiver's gain during the homing process.

[0057] Many RF environments might have one or more interfering signals within the transmitter output band. If one of these interfering signals exists within the receiver input band, a receiver might not be able to detect a signal from a transmitting golf ball. By varying the position of the receiver's input band, a particular interfering signal may be periodically avoided.

[0058] In some embodiments, the receiver center frequency varies within a band of frequencies that may be centered on the designed transmitter center frequency. In some embodiments, the receiver center frequency varies periodically at a sub-audible rate such that the position of the receiver's input band appears to slide across the transmitter's output band. The center frequency value may step among several predetermined center frequency values. Alternatively, the center frequency may sweep or traverse across a range of frequencies. The range of frequencies that the center frequency varies within may be limited such that the receiver input band always falls within a part of the transmitter's output band. By stepping or sweeping a receiver's center frequency at a sub-audible rate, the input window of the receiver moves. An interfering signal may momentarily interrupt reception while the receiver's input band captures

the interfering signal. Once the input window moves past the interfering signal, however, the receiver filters out and avoids the interfering signal.

[0059] As shown in FIGURES 4A and 4B, the receive window (defined by the receiver bandwidth BW_{Rx}) is narrower than the transmit window (defined by the transmitter bandwidth BW_{Tx}). Though the receiver bandwidth BW_{RX} might not substantially change, the placement of the receive window (or received input band) changes as the window follows the varying receiver center frequency. By implementing a receiver with an input window that steps or sweeps across a transmitter's output band, component tolerances may be relaxed. Using components that have wider tolerances and components that do not need tuning during the assembly process reduces the manufacturing costs and decreases the effects of long term component degradation.

[0060] An embodiment having a varying receiver center frequency effectively steps or slides the receiver window up or down the spectrum within the transmit window. In some embodiments, the receiver center frequency steps or slides the input window of the receiver up or down the transmit band at a sub-audible rate, e.g., 1 or 2 Hz. In some embodiments, the receive window passes across a majority of the transmitter's output window during one sub-audible cycle. In some embodiments, a sub-audible cycle follows a saw-tooth wave. For example, the input window starts at the low end of the transmitter's output band and slowly steps or slides up to the high end of the output band. Once the high end is reached, the input window is repositioned at the low end to repeat the process.

[0061] In some embodiments, a receiver uses an FM demodulator. In other embodiments, a receiver uses an AM demodulator. An AM demodulator has the advantage of being less expensive to implement than an FM demodulator. Additionally, a receiver designed with intentionally varying center frequency may be more effectively implemented with an AM demodulator than with an FM demodulator.

[0062] FIGURE 5A shows a block diagram of an exemplary embodiment of a transmitter 100. The golf ball's transmitter 100 consists of a power source (e.g., a battery) electrically attached to circuitry having an oscillator, sensor, modulator, modulation source, timer, and antenna.

[0063] The oscillator may be an LC tank circuit having an inductor L and a capacitor C. The LC tank circuit acts as a control component of the transmitter and generates a resonant frequency that may be used as an oscillator whose frequency is controlled by individually tuning the inductor and/or the capacitor. The resonant frequency of the LC tank circuit and the component values determine the actual center frequency of the transmitter circuit. The resonant frequency may be tuned by adjusting either the circuit's inductance or capacitance by methods well known to those skilled in the art.

[0064] The inductor L may be, for example, either an etched inductor or a coil inductor. In some embodiments, the inductor is etched onto a printed circuit board (PCB) thereby defining an inductive strip. An inductive strip, such as a spiral inductive strip, may be tuned by placing one or more conductive patches over the inductor trace on the PCB. Additionally, the inductive strip or coil inductor may double as an emitting antenna as shown in FIGURE 5B. The inductor couples the resonant energy from the tuned circuit to free space as propagating electromagnetic waves (radio waves). Furthermore, as the radiating area of the inductor is necessarily small, its efficiency as the transmitter may be improved by operating the device at a rather high frequency, on the order of hundreds of megahertz.

[0065] The transmitter's impact sensor may be any suitable sensor component having the ability to indicate when a sufficient amount of force has been placed on the golf ball. A sensor such as an accelerometer, shock sensor, force sensor, acceleration sensor or impact sensor may be used to indicate when the golfer has struck the golf ball and thus the desire for golf ball detection may be imminent. Alternatively, a user controllable switch may be used.

[0066] The timer and switch are used in tandem to control the ON-time of the transmitter. For example, once the sensor detects sufficient force, such as that placed on the golf ball during its launch, the timer closes the switch to initiate transmission of an FM sweeping signal.

[0067] An integrated circuit (IC) may be used to combine multiple elements of the transmitter circuitry. For example, the FM modulator, modulation source and timer functions may be integrated into a single IC chip. The IC chip may be conveniently mounted onto the PCB holding the inductive strip.

[0068] A battery, one or more accelerometers, a wide band FM radio transmitter and a timer may be integrated as a module 100 into the core of a golf ball. In some embodiments, the accelerometer turns the transmitter on, and simultaneously starts the timer when sufficient shock is detected. Once the timer has expired, the circuitry turns the transmitter off. The timer may be set to expire after a sufficient time has passed that would allow a golfer to find a wayward ball, however, it may be desired that the time not be set to such a long duration that the power source prematurely exhausts. Three to five minutes may be an appropriate length of time for ball transmission.

[0069] In some embodiments, a carrier is modulated with a modulation waveform by altering the capacitance of the LC tank circuit.

[0070] FIGURE 5B shows an LC tank circuit of a transmitter that is modulated by varying the tank circuit's capacitance. The circuit forms an oscillator comprised of a bank of capacitors having a variable capacitance C_1, a fixed capacitor having a capacitance C_2, and inductor having inductance L. The bank of capacitors and the fixed capacitor combine to form a total capacitance $C = C_1 + C_2$. The bank of capacitors, which provide a variable capacitance, is placed in parallel with the tank circuit to modify the circuit's total capacitance. The resulting resonant frequency of the circuit is $\frac{1}{2\pi\sqrt{LC}}$.

[0071] The bank of capacitors may be comprised of a number of capacitors configured in parallel. As additional capacitance is desired, capacitors with higher capacitances are switched into the circuit. Each capacitor is associated with a MOS switch that is configured to connect and disconnect the capacitor to and from the circuit. An external control signal is used to open and close the MOS switch, thereby electrically disconnecting and connecting the capacitor to the tank circuit. A desired capacitance may be derived from a signal proportional to the modulated waveform. The resulting LC tank circuit thereby generates a modulate signal. If the modulation waveform varies between two extremes, the transmitted modulated carrier signal varies between an upper bound and a lower bound of the transmitter output band.

[0072] In some embodiments, a bank of capacitors is controlled by a digital signal supplied by an up/down counter. For example, a counter counts from a low valve to a high value,

then down to the low value again. By repeating this pattern, a saw-tooth waveform may be formed. In some embodiments, the pattern repeats at an audible rate.

[0073] Some embodiments include a transmitter having a desired transmitter output bandwidth of 5 MHz at a desired center frequency of 226.25 MHz. The transmitter includes an inductor L of 22 nH and a fixed capacitor of 20 pF in parallel with a bank of capacitors that provides from 2 pF to 3 pF of capacitance. The bank of capacitors has a 9-bit control input, thereby allowing the capacitance to be controlled in steps of 2^{-9} pF. A 9-bit control input may be used to individually switch in and out any one of 512 capacitors. These component values resulted in an output band that covers approximately 223.7 to 228.8 MHz. A clock stepping the up/down counter at 25 kHz causes the total capacitance to vary from 22 pF to 23 pF, then back down to 22 pF in 100 μsec or equivalently at an audible rate of 10 kHz.

[0074] In some embodiments, the user may manually "tune" the detection unit. Manual tuning adjusts the receiver's center frequency slightly higher or lower such that the user may search for a clean spot on the spectrum with no substantial interference. Once the receiver is tuned to a quiet range within the band, the user may more easily detect the golf ball's transmitted signal. This allows the user to operate a receiver in a band that is absent significant interference when searching for the ball's transmitted signal.

[0075] The modulated signal produced by the ball can be characteristic, so that the ball's signal can be identified in the presence of interfering noise. In some embodiments, the modulation signal is a sequence of audible notes. For example, a transmitter transmits a sequence of notes until the timer 100 expires. The sequence of notes may repeat at a rate of approximately 3 cycles per second. One possible sequence may be a 440 Hz tone followed by a 660 Hz tone followed by an 880 Hz tone. Other possible signals include a continuous 5 kHz tone and a sequence of 5 kHz tones.

[0076] In some embodiments, a transmitter 100 periodically incorporates a pause in its transmission to aid in prolonging a golf ball's power supply. For example, if the golf ball, when active, transmitted with an ON-OFF duty cycle of 1:5, a golf ball's battery could be extended substantially. In such a system, when a ball has been detected, the receiver may demodulate a

series of audible tones followed by a pause. The pauses, which occur between the series of audible tones, last five times as long as the audible tones last if the duty cycle is 1:5.

[0077] As a further advantage in some embodiments, a transmitter 100 has the ability to communicate a signal indicative of the energy remaining in the transmitter's power supply. The transmitter may transmit an alternate pattern if the power supply's remaining energy or voltage is low or lower than a threshold. For example, a unique sequence, such as a 440 Hz tone followed by a 660 Hz tone, could be repeated to indicate that a golf ball's battery is substantially low. Alternatively, the rate at which the tones change from one tone to the next tone may be used to indicate the golf balls battery condition. For example, the sequence may repeat at a rate of 1 cycle per second, rather than 3 cycles per second, when the battery is low.

[0078] FIGURE 6 shows a block diagram of a receiver. The receiver may include an antenna, RF amplifier, mixer, sub-audible wave modulator, oscillator, intermediate frequency amplifier (IF amp) and detector circuit, audio amplifier, and indicator. In some embodiments, the receiver uses an AM demodulator the. In other embodiments, receiver uses an FM demodulator. In some embodiments, the antenna is a retractable antenna thereby adjusting the receiver's gain when the antenna is extracted or collapsed.

[0079] The RF amplifier receives a signal from the antenna and provides a signal to the first input of a mixer. The mixer receives a second input from an oscillator. In some embodiments, the oscillator is a variable oscillator. The frequency produced by the oscillator is varied at a sub-audible rate by a signal provided by a sub-audible wave modulator. The sub-audible wave modulator may be formed with a varactor (also known as a variable capacitance diode or a varicap). The varactor provides an electrically controllable capacitance, which may be used in adjust the frequency of the oscillator at a sub-audible rate. By varying the second input into the mixer, the input window of the receiver effectively moved across a band at a sub-audible rate.

[0080] The mixer produces an intermediate frequency signal, which is amplified and detected by the IF amp and detector circuit. The detector circuit may be a logarithmic amplitude detector. The signal from the detector may be amplified and provided to an indicator, such as a

speaker, an LED or the like. An optional audio amplifier may be used to amplify the detected signal prior to providing the signal to the indicator.

[0081] Radio location by homing in on a transmitter while listening for audible signal strength may be very difficult using a traditional FM receiver having a front-end limiting stage. A limiting-stage automatically adjusts the amplitude of the received signal. If a limiting stage is used, the audible signal strength does not appreciably vary as the receiver approaches the transmitter. The receiver used in this invention can benefit by replacing the limiting stage with a user-controlled, variable gain stage prior to the detector allowing the user to adjust the receiver's sensitivity and overall receiver loudness. Alternatively, the antenna may be a retractable antenna. The gain of the receiver may be adjusted by adjusting the length of the antenna. In addition, an operator's hand may cup the detection unit, thereby reducing the overall effectiveness of the antenna. As an operator nears the transmitting ball, retracting and/or cupping of the antenna reduces the gain of the antenna, thereby allowing an operator to detect a golf ball residing within a very short radius.

[0082] FIGURE 7 shows a plan view of a printed circuit board (PCB) having an etched inductor in accordance with the present invention. The inductor is connected by vias (or through holes) to the component side of the PCB. Also shown is a metallic sticker that may be attached with an insulating adhesive to the etched inductor to tune or alter the inductor's inductance. Alternatively, the etched inductor may be replaced with a coil of wire having a small number of turns. Some coil inductors have as few as two to three turns with a small diameter, such as 8 millimeters. The coil's inductance may be tuned by bending the coil turns prior to encapsulation.

[0083] In the production of the golf ball core circuitry, an assembled printed circuit board, attached to its battery, may be allowed to transmit while the natural frequency of the assembled LC tank circuit is measured. Component values for the capacitor and for the etched inductor may be intentionally chosen such that the LC tank circuit resonates at a frequency that is slightly lower than the intended frequency of operation.

[0084] FIGURES 8 and 9 show views of a printed circuit board (PCB). FIGURE 8 shows a cross sectional view of a PCB according to some embodiments of the present invention. FIGURE 9 shows a prospective view of an embodiment of a transmitter 100 including its PCB

electrically connected to a battery. The etched inductor may face away from the battery to aid in efficient radiation of the transmitted signal.

[0085] Examples provided are meant to be exemplary and not limiting. The following claims define the scope and limits of the invention.